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Naval Health Research Center

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Summary

Background

Department of Defense policy mandates physical fitness assessments that include tests of cardiorespiratory fitness. Run tests are the usual method of meeting this requirement. Some individuals must be medically waived from the run because they are at risk for lower extremity injuries. Elliptical trainers (ETs) provide a test modality capable of subjecting the cardiorespiratory system to challenges equal to those in running but with less ground reaction force. Previous investigations indicated that exercise bouts on a Life Fitness ET provided a valid alternative to run tests.

Objective

The present investigation was undertaken to compare the Life Fitness trainer to the Nautilus Model E916 and Precor Model EFX 556 machines. The comparison was made to ensure that test validity was not limited to the Life Fitness machine.

Methods

Ten active duty U.S. Navy personnel (8 men, 2 women) performed 12-min exercise bouts on the Nautilus Model E916 and Precor Model EFX 556 ETs. Resistance varied from 5 to 15 for the Precor Model EFX 556 and 4 to 14 for the Nautilus Model E9 16. The energy expenditure during each bout was determined by open-circuit spirometry. Measured energy expenditure was computed from the oxygen uptake rate and respiratory exchange ratio during the last 6 min of each bout. Preliminary analyses demonstrated that the energy expenditure was steady state during this period. The relationship between the machine calorie reports and the measured energy expenditures was evaluated by analysis of covariance and analysis of variance.

Results

Machine calorie reports were strongly related to measured energy expenditure. The slope of the pooled regression line was not significantly different from 1.00. The machine calorie reports were higher than the measured energy expenditures for all three machines. The magnitude of bias differed between machines.

Conclusions

All three ET models provided valid, but biased, reports of energy expenditure. The machine calorie reports from all three machines can be converted to equivalent run times using an algorithm developed in the earlier Life Fitness CT 9500 HR evaluation. This application requires adjustments for differences in the magnitudes of bias for the Nautilus Model E916 and Precor Model EFX 556 relative to the Life Fitness CT 9500 HR. All of the biases are too small to be important when the machines are used to monitor long-term energy expenditure as part of a regular exercise program.

The Department of Defense requires all military services to conduct physical fitness assessments. The assessments must include an evaluation of cardiorespiratory fitness. A distance run is commonly used to fulfill this requirement. Performing a distance run can exacerbate some medical conditions. As a result, some personnel receive medical waivers from running.

The need for waivers is related to the ground contact forces involved in running. These forces increase the risk of musculoskeletal damage during the test. An elliptical trainer (ET) is an exercise machine that eliminates the shocks associated with ground contact. Despite this difference, ET bouts can generate physiological demands equivalent to those incurred in running. Therefore, the U.S. Navy has undertaken an evaluation of ET exercise bouts as an alternative to the 1.5-mi run in the Physical Readiness Test (PRT).

Prior research has established that ET bouts can provide valid measures of cardiorespiratory fitness. The strongest evidence for this claim is provided by demonstrations that ET bouts can be used to measure maximal oxygen uptake (VO_{2max}). Studies comparing ET VO_{2max} with treadmill (TM) VO_{2max} measured on a treadmill have produced strong associations for ET protocols requiring maximal exertion (Dalleck, Kravitz, & Robergs, 2004) and protocols extrapolating from submaximal exertion to VO_{2max} (Dalleck, Kravitz, & Robergs, 2006) protocols. The average VO_{2max} was the same for ET and TM in these studies and two additional studies (Mercer, Dufek, & Bates, 2001; Wiley, Mercer, Chen, & Bates, 1999). A related finding indicates that matched ET and TM training programs produce comparable changes in VO_{2max} (Egana & Donne, 2004).

Other research provides additional reason to believe that ETs are a valid alternative to standard running tests. Several studies have compared oxygen uptake during exercise bouts that were matched for subjective exertion. Some studies indicated ET = TM on oxygen uptake (Crommett, Kravitz, Wongsathikun, & Kemerly, 1999; Mercer et al., 2001; Pecchia, Evans, Edwards, & Bell, 1999; Porcari, Zedaker, Naser, & Miller, 1998). Others have found that the oxygen uptake associated with a given level of perceived exertion is higher during ET bouts than TM bouts (Batte, Darling, Evans, Lance, Olson, & Pincivero, 2003; McAllister et al., 2005). A study of coronary artery disease patients found ET = TM for oxygen uptake at a higher exertion level, but ET > TM at a lower exertion level (Sweitzer, Kravitz, Weingart, Dalleck, Chitwood, & Dahl, 2002). On the whole, the evidence indicates that during exercise bouts of comparable subjective intensity, ET \geq TM. Porcari, Zedacker, Naser, and Miller (1998) provided a possible explanation for the difference by showing that the vertical ground reaction forces for ET were less than half the reaction forces observed in TM running.

The research summarized in the two paragraphs above demonstrate that ETs can produce maximal activation of the cardiorespiratory system. The evidence also indicates that ETs produce oxygen consumption rates comparable to treadmill running in submaximal bouts that are matched for exertion. An ET may produce this uptake with lower perceived exertion. The central theme of the previous research is that ETs are a valid alternative to running as a means of inducing cardiovascular demands.

The evidence does not address an issue that is central to the use of ETs as fitness test devices. Those applications quantify performance on the basis of information provided by the ET. The reported calorie expenditure is the logical index of performance when testing. No previous study has addressed the accuracy of calorie reports, nor has previous research examined the problem of converting ET performance into equivalent running performance.

This evaluation is one in a series of investigations to answer basic questions about the feasibility of using ETs as testing devices. Previous ET evaluations focused on one model, the Life Fitness CT 9500 HR. This focus was chosen because this machine was the ET that was most widely available in the Navy when the evaluations were undertaken. The first evaluation demonstrated that different machines produced virtually identical calorie readouts during a standardized exercise bout. A second evaluation demonstrated that the machine calorie report was strongly related to measured energy expenditure evaluated by laboratory methods (i.e., indirect calorimetry). However, the machine report was consistently higher than the laboratory measurement. The third evaluation related machine calorie expenditure reports from a 12-min ET bout to 1.5-mi run times. Participants were instructed to exert themselves just as they would during the 1.5-mi run on the PRT. The relationship between the machine calorie reports and run times was as strong as the relationship typically seen when laboratory measures of maximal oxygen consumption are used to predict run times. This point is important because the laboratory measures in question are the accepted gold standard for measuring cardiorespiratory fitness. Secondary analysis of the relationship of running performance with machine calorie reports provided additional evidence that the reports were higher than actual energy expenditure.

The evaluations of the Life Fitness CT 9500 HR machine supported two important conclusions. First, ET bouts can be valid tests of cardiorespiratory fitness. Second, machine calorie reports are biased. Parker, Griswold, and Vickers (2006) provided details of the earlier evaluations and an algorithm to convert machine calorie reports into equivalent run times.

This report describes the evaluation of the Nautilus Model E916 and Precor Model EFX 556 ETs. These ET models are available at some Navy commands that may not have Life Fitness CT 9500 HR machines. The evaluation focuses on the accuracy of machine calorie reports. If these machines are like the Life Fitness CT 9500 HR machine, these reports will be accurate except for bias. If so, machine differences would be limited to bias differences. Performance during ET bouts can be matched across machines by adjusting for bias differences. This result would permit all three machines to be used in PRT assessments based on the Life Fitness CT 9500 HR conversion algorithm.

METHODS

Participants

Eight (8) men and 2 women participated in the study. All were active-duty U.S. Navy personnel. All participants were volunteers who gave voluntary informed consent to participate. The evaluation complied with all human protection requirements.

Elliptical Trainer Models

The Nautilus Model E916 and Precor Model EFX 556 machines were studied. Each machine permits the user to vary the resistance and stride rate during exercise bouts. Calorie expenditure is reported continuously on the Nautilus Model E9 16. Precor Model EFX 556 provides continuous calorie reports when locked into that mode, as was the case in this evaluation.

Oxygen Consumption Measurements

Oxygen consumption and respiratory exchange ratio (RER) were recorded breath-by-breath during each exercise bout. The measures were provided by a standard, commercially available open-circuit spirometry system (Vista SX, VacuMed, Ventura, CA). Prior to the bouts, participants were fitted with a face mask, which was used with the open-circuit spirometry system. The system was calibrated against gas standards and volume standards before each data collection session. A Parvo Medics TrueMax 2400 metabolic measurement system (Salt Lake City, UT) was used for 4 exercise bouts during the period of repair for the VacuMed system.

Energy Expenditure Computations for Oxygen Consumption

Oxygen uptake was converted to measured energy expenditure. The conversion employed the oxygen uptake (VO_2) measurements and RER. RER was needed because the caloric yield from consuming a milliliter of oxygen depends on the mixture of fats and carbohydrates being burned. RER is an indicator of the relative proportions (McArdle, Katch, & Katch, 2001). Analysis of the RER conversion values given in Table 8.1 of McArdle et al. (2001) produced the equation:

$$\text{Measured Energy Expenditure} = \text{VO}_2 * [3.816 + (1.231 * \text{RER})] \quad (\text{Equation 1})$$

When VO_2 is measured in liters per minute, Equation 1 converts oxygen consumption to energy output in $\text{kcal} \cdot \text{min}^{-1}$.

The cumulative energy expenditure for the bout was obtained by multiplying the energy expenditure for the last 6 min by 2 to obtain cumulative energy expenditure for the 12-min bout. During this time period, aerobic processes should have provided nearly all of the required energy. Parker et al. (2006) found that uptake was stable during the last 6 min of each bout completed in their study. Preliminary analyses of the data in this study indicated that the same was true for the Precor EFX 556 and Nautilus E916 bouts. Also, the number of breaths taken during this time period was, once again, sufficient to obtain a stable measure of energy expenditure. Therefore, the breath-by-breath energy expenditure rates were summed over the last 6 min of each bout. This sum was multiplied by 2 to obtain the measured energy expenditure for the entire 12-min bout. The summation was limited to the steady-state phase of the exercise bout because anaerobic energy processes contribute a substantial proportion of the total energy during the initial period of exertion. However, given constant resistance and stride rate, the energy requirements were constant throughout the bout. Aerobic energy represented this constant rate only after a steady state was reached. Steady-state measures in submaximal exertion are sometimes estimated from a 1- or 2-min sample of oxygen uptake. In this case, the summation over 6 min reduced the sampling variance of the measurements by increasing the sample size for the computations.

Procedures

Participants came to the exercise testing laboratory 3 times. The research design called for the completion of 3 or 4 exercise bouts during each visit for a total of 10 bouts. If all participants had completed all of the schedule bouts, a total of 100 exercise bouts would have been conducted. The data reported in this paper represent 75 completed bouts. Missing bouts were most often caused by the researchers stopping the bout because the participant's physiological response to exercise suggested that he or she would be unable to achieve a stable level of oxygen consumption during the bout (15 bouts). Some bouts were not started because the participant had not been able to complete a bout of similar intensity earlier in the series (4 bouts), because of technical problems encountered during the bout (5 bouts), or because the participant was unable to schedule a return to the laboratory (1 bout).

During each bout, the participant wore a light face mask hooked to the calorimetry system to monitor gases. Each bout consisted of a 5-min warm-up with resistance set at 2 for the Nautilus Model E916, or 3 for the Precor Model EFX 556. During the warm-up for the first bout, participants set a personally comfortable stride rate. Participants were asked to maintain this rate as well as possible during subsequent warm-up sessions and bouts. After warm-up, the resistance setting was increased to the resistance for the bout. The settings were 4, 6, 9, 11, and 14 for the Nautilus Model E916, and 5, 8, 10, 12, and 15 for the Precor Model EFX 556. The participant then exercised for 12 min. At the end of each bout, participants were asked to cool down for 5 min.

The importance of a steady stride rate during each bout was emphasized. A consistent stride rate meant a constant work rate during the bout. A constant work rate made it possible to achieve steady-state oxygen uptake. Steady-state uptake made it possible to determine the energy expenditure rate for the bout. Bouts were stopped if there was reason to believe that the participant would not reach a steady state by 9 min into the bout.

Life Fitness CT 9500 HR Data

Parker et al. (2006), Study 2, collected comparable data for the Life Fitness CT 9500 HR ET. Other than the model of trainer, the manipulation of stride rates was the primary difference between the methods in that evaluation and the present methods. Participants were required to exercise at 50, 60, 70, or 80 revolutions per minute. These rates correspond to stride rates of 100, 120, 140, and 160 strides per minute. Stride rate was not manipulated in the present evaluation because the data from the prior study indicated that the relationship between machine reports and calorimetry measures was not affected by stride rate. Including the 72 exercise bouts completed in the earlier Life Fitness CT 9500 HR evaluation provided a direct comparison of the Life Fitness CT 9500 HR machine with the Nautilus Model E916 and Precor Model EFX 556 machines.

Analysis Procedures

All analyses were performed using the SPSS-PC computer program, Version 12.0 (SPSS, Inc., Chicago, IL). The primary data analysis procedure was an analysis of covariance (ANCOVA). The groups in this analysis were defined by which ET had been used for the exercise bout. Machine calorie reports were the covariate. Measured energy expenditure was the dependent variable. Preliminary analyses dealt with several issues that required attention to ensure that valid inferences could be drawn from the primary analyses. Appendix A describes these analyses.

RESULTS

The machine calorie report was strongly related to the measured energy expenditure, $F(1,143) = 452.15, p < .001$. This predictor accounted for 51.4% of the variance in measured expenditures. The regression slope was $b = 1.025$ (95% confidence interval, .930-1.12). The slope was not significantly different from 1.000, $t(143) = 0.52, p > .302$.

The adjusted means for the ET machines differed significantly, $F(2,143) = 24.45, p < .001$. The machine report for each machine was higher than the measured energy expenditure for each machine. The intercepts for the equations for the different machines were: Nautilus Model

E9 16, -16.38; Precor Model EFX 556, -28.76; Life Fitness CT 9500 HR, -37.41. The intercept for each machine was significantly less than zero (Nautilus Model E9 16, $t = -2.44$, $p < .023$; Precor Model EFX 556, $t = -4.22$, $p < .001$; Life Fitness CT 9500 HR, $t = -4.29$, $p < .001$). Machine differences explained 5.2% of the variance in measured energy expenditure.

Difference scores provide a suitable summary description of machine differences.¹ When analyzed in a one-way analysis of variance (ANOVA), machine differences were statistically significant, $F(2,144) = 38.46$, $p < .001$. This simplified model produced bias estimates of 13.21 kcal per bout for the Nautilus Model E916, 25.72 kcal per bout for the Precor Model EFX 556, and 32.95 kcal per bout for the Life Fitness CT 9500 HR.² These differences have been labeled “biases” in Figure 1 to indicate that they represent a consistent tendency for the ETs to overestimate energy expenditure.

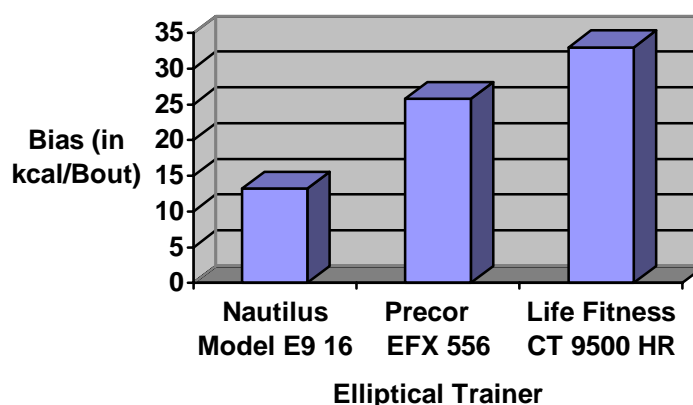


Figure 1.
Bias Estimates for Elliptical Trainer Machines

Bias differed between machines. Tukey’s Least Significant Difference test indicated that the bias for each machine differed significantly ($p < .001$) from the biases for the other two machines.

Machines were equally accurate after allowing for bias. If measurements were perfectly accurate except for bias, the difference for every bout would literally equal the bias for the machine. The variation in bias estimates for each machine therefore is an index of measurement error. The variation in difference scores was clearly greater than zero and comparable across

¹ Difference scores were appropriate because the regression slope in the ANCOVA was not significantly different from 1.000 (cf., Anderson, Auquier, Hauck, Oakes, Vandaele, & Weisberg, 1980). Models with fewer parameters are more parsimonious (Popper, 1959). Difference scores eliminate the need for the regression slope as a model parameter. The difference model is statistically justified by the slope findings and philosophically justified on the grounds of greater parsimony.

² The sign of the differences is positive because the calorimetry values were subtracted from the machine reports. The adjusted means in the ANCOVA model had the opposite sign because the analysis effectively subtracted the machine report from the calorimetry value. The absolute values of the bias estimates were comparable. The average difference score is slightly smaller than the absolute value of the intercept because the slope of the ANCOVA regression line was slightly higher than 1.000.

machines (Nautilus Model E9 16, $SD = 11.82$ kcal, Precor Model EFX 556, $SD = 11.44$ kcal, and Life Fitness CT 9500 HR, $SD = 11.01$ kcal). Tests for homogeneity of variance indicated that these standard deviations were not significantly different (Levene statistic = .051, $p > .950$). The best estimate of that accuracy is the pooled within-group standard deviation ($SD = 11.33$ kcal).

DISCUSSION

This study evaluated the accuracy of machine calorie reports for three ET models. The similarities and differences between ET machines are readily summarized.

- All machines accurately express the *differences* in energy expenditure across exercise bouts. The fact that the slope of the regression of measured energy expenditure on machine reports was not significantly different from 1.000 supported this claim.
- Each machine produces biased calorie reports. Machine reports of calories expended were higher than the measured energy expenditure for all 3 machines. This bias was evident in both the adjusted group means and the average difference scores.
- Bias magnitude is machine dependent. Analyses demonstrated significant machine differences in both the ANCOVA and ANOVA procedures.
- All machines have comparable measurement errors. The standard deviations for difference scores supported this point.

The similarities and differences leads to a simple overall summary: *The machines examined here are interchangeable except for differences in bias.*

The results imply that the Parker et al. (2006) algorithm can be used with all 3 ETs. Although the algorithm is based on Life Fitness CT 9500 HR data, it applies to other machines if their calorie reports can be matched to the calorie report that would have been obtained if the bout had been performed on a Life Fitness CT 9500 HR machine. Because machine differences are limited to the magnitude of bias, matching can be achieved by adjusting for those differences. For example, the Nautilus Model E916 bias is 19 kcal less than that the Life Fitness CT 9500 HR bias. If two exercise bouts performed on these machines generated identical true energy expenditures, the Life Fitness CT 9500 HR calorie report would be 33 kcal higher than the true value. The Nautilus Model E916 calorie report would be 13 kcal higher. The Nautilus Model E916 report can be converted to the equivalent Life Fitness CT 9500 HR report by adding 20 kcal. Parallel argument leads to the conclusion that Precor Model EFX 556 results can be matched to Life Fitness CT 9500 HR results by adding 7 kcal. The algorithm for converting Life Fitness CT 9500 HR results to run time equivalents then can be applied to the converted Nautilus Model E916 and Precor Model EFX 556 results.

Application to Testing Situations

Bias corrections are important. The algorithm for converting ET performance to its run time equivalent has two basic components. The first component converts the machine calorie report into a raw run time estimate. In this part of the algorithm, the energy required to run 1.5 mi is determined based on the person's weight (i.e., 1.09 kcal/lb). The machine calorie report from the ET bout provides an estimate of the rate at which the required energy can be generated. This energy production rate is the machine calorie report divided by 12. The raw run time estimate is the energy requirement divided by the energy production rate. Stated formally

Energy Requirement = $1.09 * \text{Weight (in pounds)}$

Energy Production Rate = $\text{Machine Calorie Report}/12$

Raw Run Time Estimate = $\text{Energy Requirement}/\text{Energy Production Rate}$

These steps can be combined to produce a simple equation to convert weight and the machine calorie report into the raw run time estimate. The equation is

$$\text{Raw Run Time Estimate} = (13.08 * \text{Weight}) / \text{Machine Calorie Report}$$

Note that this equation yields the initial raw run time estimate. This point must be kept in mind to avoid misinterpreting the results of these computations.

The raw run time estimate will be too fast. This initial estimate is too fast because it is based on the machine calorie report. That report is higher than the actual calorie expenditure determined by indirect calorimetry. As a result, the energy production rate determined from the machine calorie report is too high. The rate is too high because of the bias in the machine calorie reports.

The run time conversion algorithm adjusts the raw run time estimate. The adjustment eliminates the effect of bias in the machine calorie reports. Parker et al. (2006, Study 3) provided empirical evidence that the raw run time estimates were too fast. Several methods of correcting for this tendency were evaluated. The best method was to add a gender-specific constant to the raw run time estimate. The constant, which was determined empirically, was 1:08 min for men and 2:15 min for women. This adjusted value is the *run time equivalent* for the ET bout.

The algorithm for converting machine calorie reports to run time equivalents was designed for the Life Fitness CT 9500 HR ET. This adjustment bases raw run time estimates on Life Fitness CT 9500 HR calorie reports. The calorie reports for the same bout would be lower if the bout had been performed on the Nautilus Model E916 and Precor Model EFX 556 ETs. If the simple calorie outputs from Nautilus Model E916 and Precor Model EFX 556 machines are used in the computation, the raw run time estimates will be slower than they would be if the same person had performed the same exercise bout on the Life Fitness CT 9500 HR ET.

The machine bias differences are the reason that the raw run time estimate depends on which machine is used. Times will be slower times because the lower calorie reports produced by the Nautilus Model E916 and Precor Model EFX 556 machines will result in lower values for the energy production rate. The total energy requirement for a 1.5-mi run does not change, so the lower energy production rates mean that the estimated time required to generate the energy will be longer.

It might be possible to ignore the effects of differential bias in the machine calorie reports. This course of action would be reasonable if the differences in bias had trivial effects on run time estimates. To assess this possibility, *raw run time estimates* were computed for a set of hypothetical ET bouts.³ The hypothetical bouts were defined by combining a defined set of hypothetical true energy expenditures with a set of weights for test participants. The true energy expenditure refers to the value that would have been obtained from open-circuit spirometry during the bout. The values for this hypothetical true calorie expenditure were chosen to cover the range from 150 kcal to 275 kcal in 25 kcal increments. The chosen weights for the hypothetical test participants ranged from 125 pounds to 250 pounds in 25 pound increments. The hypothetical

Table 1. Effects of Bias on Raw Run Time Estimates (in min:sec)

Weight, lb	Measured Energy Expenditure (in kcal) ^a					
	150	175	200	225	250	275
125 L ^b	8:56	7:52	7:01	6:20	5:47	5:19
P ^b	9:17	8:08	7:14	6:31	5:55	5:26
N ^b	10:02	8:42	7:41	6:52	6:13	5:41
150 L	10:43	9:26	8:25	7:36	6:56	6:22
P	11:09	9:46	8:41	7:49	7:07	6:37
N	12:02	10:26	9:13	8:14	7:28	6:49
175 L	12:31	11:00	9:49	8:52	8:05	7:26
P	13:01	11:23	10:08	9:07	8:17	7:36
N	14:02	12:11	10:45	9:37	8:42	7:57
200 L	14:18	12:35	11:14	10:08	9:14	8:29
P	14:52	13:01	11:35	10:25	9:29	8:41
N	16:03	13:55	12:17	10:59	9:57	9:05
225 L	16:05	14:09	12:38	11:25	10:24	9:34
P	16:43	14:38	13:01	11:44	10:46	9:47
N	18:04	15:39	13:49	12:22	11:11	10:13
250 L	17:52	15:43	14:02	12:40	11:33	10:37
P	18:35	16:16	14:28	13:02	11:51	10:53
N	20:04	17:23	15:21	13:44	12:26	11:21

^aEnergy expenditure that would be obtained from open-circuit spirometry.

^bElliptical trainer model with L = Life Fitness CT 9500 HR, P = Precor Model EFX 556, and N = Nautilus Model E9 16.

Note. Table entries are *raw time estimates* for *hypothetical* bouts defined by the combination of actual energy expenditure (rows) and weight of the test subject (columns). Time is given in minutes and seconds. The gender adjustments of 1:08 for men and 2:15 for women defined in Parker et al. (2006) would have to be added to obtain the actual run time equivalents. See text for details.

true energy expenditure values defined the columns in Table 1; the hypothetical participant weights defined the rows in Table 1.

Bias effects were added to the true energy expenditures to obtain ET calorie reports. Those calorie reports were used to compute raw run time estimates for the hypothetical ET bouts. Machine calorie reports for hypothetical bouts on the Life Fitness CT 9500 HR ET were computed by adding 33 kcal to the actual energy output. Thus, the computations for this machine were carried out for machine calorie reports of 158, 183, and so on. Machine calorie reports for hypothetical bouts on the Precor Model EFX 556 were obtained by adding 24 kcal to the hypothetical true energy output. Machine calorie reports for the Nautilus Model E916 were

obtained by adding 13 kcal to the hypothetical true energy output. Raw run time estimates based on these biased values were computed for each machine-weight-energy output combination. Table 1 presents the raw run time estimates for all 3 machines grouped by actual energy expenditure (rows) and weight (columns).⁴

The contents of Table 1 can be deciphered by noting several major trends. First, each row of the table indicates the effect of better performance during the ET bout. The bouts within a row represent the performance of a test subject of a given weight on a given ET model. Within each row, energy expenditure during the bout increases from left to right within the table. Within each row, the raw run time estimate decreases from left to right. This trend indicates that better performance on the ET produces a faster raw run time estimate.

The second major trend concerns the effect of weight. This trend is evident when performance is held constant. Performance is constant within the columns of the table. The effect of weight is properly defined by examining the raw run time estimates for a given machine within a column. For example, if the hypothetical exercise bout were performed on a Nautilus Model E9 16, a measured energy expenditure of 200 kcal would produce a machine calorie report of 209 kcal. Given this calorie report, the raw run time estimates would be 7:41 min for a 125-lb test subject, 9:13 min for a 150-lb test subject, 10:45 min for a 175-lb test subject, and so on.

The third major trend is composed of machine effects. These effects are evident in comparisons of the 3 entries in each cell of the table defined by a weight-energy expenditure combination. For every combination, the raw run time estimate is fastest for the Life Fitness CT 9500 HR machine. The Precor Model EFX 556 value is the second fastest. The Nautilus Model E916 produces the slowest time estimate. In other words, raw run time estimates correspond to the following order: Life Fitness CT 9500 HR < Precor Model EFX 556 < Nautilus Model E9 16. This order is determined by the machine bias differences in bias. After bias adjustment, the Life Fitness CT 9500 HR machine will have the highest reported calorie expenditure followed by the Precor Model EFX 556 and Nautilus Model E916 machines. The energy production rate will follow this same order. Using those rates as the denominators for estimating run time reverses the order.

The machine differences in raw run time estimates are critically important for any testing procedure. If differences were small, adjustments for machine biases would not be needed. In fact, the machine differences for the hypothetical set of bouts in Table 1 range from 7 s to 2:12 min. The minimum occurs when comparing times for the Life Fitness CT 9500 HR and Precor Model EFX 556 machines for a 125-lb test subject who produces 275 kcal during the 12-min bout. The maximum occurs when comparing times for the Life Fitness CT 9500 HR and Nautilus Model E916 machines for a 250-lb test subject who produces 150 kcal during the 12-min bout. In general, the differences are large enough to affect PRT results.

Machine differences are contingent on weight and fitness. Machine effects are larger for heavier individuals. If the energy outputs shown in the table represent the best the test taker can

⁴The analysis was limited to the raw run time because the machine calorie report is used only in this part of the algorithm. The basic computation is the same for men and women, so focusing on the raw run time estimate also eliminates the need for adding sex differences to the table.

⁴ The table presents the raw run time estimate because this part of the algorithm is the same for men and women. Therefore, a single table of raw run time estimates applies to all test takers. A table of run time equivalents would require separate sections for men and women. The only difference between the sections would be the size of the adjustment to the raw run time estimate (see note with table).

do, higher calorie reports correspond to greater fitness. Under this assumption, machine effects are larger for less-fit individuals. When combined, the machine effect will be greatest for heavy individuals with low levels of fitness.

Conclusions

Different ET machines can be used for fitness assessment in the U.S. Navy PRT, provided that the application allows for differences in bias. The three machines examined in this study performed similarly except for that difference. Overall, each machine accurately tracked differences in measured energy expenditure. Each machine produced comparable measurement errors (i.e., differences between measured and reported calorie expenditure after allowing for bias). The magnitude of the bias in machine calorie reports was the only important difference between machines evident in this evaluation.

The fact that machine differences were limited to bias makes it possible to apply the algorithm developed for the Life Fitness CT 9500 HR ET to all 3 machines. The application requires matching the calorie reports from the Precor Model EFX 556 and Nautilus Model E916 machines to what would have been observed if the same bout had been performed on the Life Fitness CT 9500 HR. The requisite matching is achieved by adding 20 kcal to Nautilus Model E916 reports and 7 kcal to Precor Model EFX 556 reports. The resulting energy expenditure estimates will yield appropriate raw run time estimates. The conversion to an equivalent run time then can be completed by adding the required gender-specific adjustments.

Adjustments for machine differences are required for fair testing. The full procedure for converting ET performance to a run time equivalent run time would be:

1. Conduct a 12-min ET bout.
2. Match the machine calorie report to the corresponding Life Fitness CT 9500 HR value.
 - a. Leave Life Fitness CT 9500 HR values unchanged.
 - b. Add 20 kcal for bouts on Nautilus Model E9 16.
 - c. Add 7 kcal for bouts on Precor Model EFX 556.
3. Divide the calorie report from Step 2 by 12 to get energy production rate in kcal/min.
4. Multiply the test subject's weight in pounds by 1.09 to determine the total energy required to run 1.5 mi.
5. Divide the result of Step 4 by the result of Step 3 to obtain the raw run time estimate in a decimal format.
6. Multiply the decimal portion of Step 5 by 60 to convert it to seconds. The result is the raw run time estimate expressed as min:sec.
7. Obtain the run time equivalent for the ET bout by adding 1:08 min for a male test subject or 2:15 for a female test subject.
8. Use the run test standards in the PRT instruction to convert the run time equivalent to a PRT score.

The gender adjustments to the raw run time estimates were empirically determined by Parker et al. (2006).

The conclusion that ETs are biased is not a criticism of any ET machine. ETs are designed as exercise devices. For that purpose, biases of the magnitude described here are unimportant. For example, the Nautilus Model E916 bias is 1.1 kcal/min (i.e., 13.2 kcal per 12-min bout). If a person were exercising to lose weight, he or she would have to exercise for 3,182

min before the cumulative effect of bias would amount to 1 lb of fat loss (i.e., 3,500 kcal). Exercising 30 min per day, a 1-lb error would accumulate after 106 exercise sessions. If the individual exercises 5 days each week, the cumulative error would equal 1 lb of fat only after 21 weeks of exercise. The corresponding periods for the Precor Model EFX 556 and Life Fitness CT 9500 HR machines would be 11 weeks and 8 weeks, respectively. An error of 1 lb every 2 to 5 months clearly is not critical in the context of long-term exercise goals.

To summarize, this evaluation extended the evidence that ETs accurately assess differences in energy expenditure. However, this evaluation also extended the evidence that machine calorie reports are biased. The magnitude of bias depends on the machine, but performance on different machines can be matched to allow for the bias differences. The algorithm developed to convert Life Fitness CT 9500 HR performance to its run time equivalent can be applied to the Nautilus Model E916 and Precor Model EFX 556 machines after adjusting for bias differences.

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Appendix A. Results of Preliminary Data Analyses

Carryover Effects

Measured energy expenditure during the warm-up period was analyzed to evaluate the presence of a carryover effect. Carryover effects would be present if the completion of one bout affected the results of a subsequent bout. Carryover effects might occur as a result of learning to be more efficient on the ET. Carryover effects might occur as a result of cumulative fatigue during a series of bouts.

Carryover effects arguably would be absent if a series of standardized bouts were completed and all of the bouts produced the same results. With allowance for machine differences, the warm-up for each bout provided a standardized challenge. If carryover effects were absent, the energy expenditure should be the same during each warm-up. The energy expenditure rates over the last half of each warm-up period were analyzed to determine whether this was the case. The energy uptake for the bout should be nearly constant during this period.

The average rate was significantly different for only 3 of 10 participants. The average proportion of variance explained was only 3.1% (2.4% with 1 outlier case eliminated). These differences that occurred did not allow for the fact that the data represented a time series. Serial correlations in time series lead to underestimation of variability. Two of the three nominally significant results were close to nonsignificance ($.022 < p < .046$), so a better variance estimate might have rendered them nonsignificant. However, even if the results were accepted as significant, each analysis involved between 5 and 8 trials. When the variance explained by trial-to-trial differences is considered relative to the number of degrees of freedom in the analysis, the typical value was less than 0.5% per degree of freedom. Cohen (1988) suggests that 1% is the minimum value for a theoretically or practically important effect. The differences still might have been important if they had represented any consistent trends suggesting fatigue or experience effects. If any such trends were present, they were not evident in the patterns of mean values. The only obvious potential explanation was that stride rates varied somewhat from one bout to the next. Stride rate differences would produce differences in energy expenditure because they are equivalent to covering different distances during the test.

The differences between machine calorie reports and measured energy expenditure provided another basis for estimating carryover effects. Differences were analyzed as a function of trial order. Order was not related to the size of the differences, $F(9,63) = .60, p > .789$.

The analysis of potential carryover effects provided no evidence that these effects were present. The rest periods between bouts and the minimization of exertion appear to have been sufficient to avoid cumulative effects of exercise on performance.

Evaluation of Steady-State Requirements

The research was designed to elicit energy expenditure rates that were substantially less than the maximum for each participant. When a submaximal bout continues for a period of time, the exercise reaches a steady state for oxygen uptake. In the present context, steady-state uptake by the end of the exercise bout was a requirement for accurate estimation of energy expenditure. The energy expenditure for an ET bout conducted at a given stride rate and resistance is constant throughout the bout. If a steady state is achieved by the end of the bout, the energy expenditure during that period is an estimate of the expenditure throughout the bout. Parker et al. (2006) found that steady state was achieved in the last 6 min of bouts in the earlier Life Fitness CT 9500

HR assessment. Temporal trends in oxygen uptake were evaluated over this same period to assess steady state in the current work.

ANCOVA procedures tested for steady state. The procedures employed trial as the group variable and time as the covariate. A separate analysis was conducted for each participant. The findings were evaluated in terms of variance explained. The large number of data points representing each trial meant that any significance test would be of limited value.

The analyses indicated that trial by time effects were minimal. Differences in the regression slopes accounted for <1.0% of the variance in 7 of 10 cases. The maximum variance explained was 1.7%. In all cases, the analysis involved 5 to 8 degrees of freedom, so the variance per degree of freedom was less than 0.2% in every case. These effect sizes were too small to be important. The effects that were nominally significant achieved this status only because the nominal sample sizes were large (i.e., between 990 and 2005 data points).

The common regression slope model indicated a significant effect of time for 1 participant ($p < .017$), marginal effects ($p < .068$ and $p < .084$) for 2 participants, and clearly nonsignificant trends ($p > .447$) for all other participants. The sole significant effect accounted for only 0.4% of the variance. This value was well below Cohen's (1988) 1% boundary for a meaningful effect. The overall evidence therefore indicated that a model that assumed steady state during the last 6 min of each bout was reasonable.

Comparison of Alternative Dependent Variables

The earlier Life Fitness CT 9500 HR evaluation used a previous version of the Vista SX. That version did not automatically report the cumulative energy expenditure during each exercise bout. The previous evaluation determined energy expenditure from breath-by-breath computations performed offline. The computations combined the VO_2 and RER data for each breath into energy expenditure rates.

The updated Vista SX software provided a cumulative energy expenditure estimate for each breath. Subtracting the cumulative energy value from the preceding breath from that for the current breath provided Vista values that were comparable to the breath-by-breath computations used in the prior analyses. Comparing the two computations provided a verification of the accuracy of the prior methods.

The cumulative values for each trial differed by at most 0.62 kcal. The average absolute difference was much smaller at 0.17 kcal. For an entire bout the choice between the Vista SX values and the computed values would be at most 1.24 kcal, but typically only 0.34 kcal. The average discrepancy of 0.34 kcal is unimportant in the context of overall bout calorie reports, ranging from 77 kcal to 225 kcal, with an average of 131 kcal.

Test for Parallelism of Regression Lines

Parallel regression lines are an underlying assumption in ANCOVA. The assumption is tested by comparing two models. One model treats the slope of the equation relating the covariate to the dependent variable as a constant. The regression line applied to each group combines this slope with a group-specific intercept. The other model allows both the slope and intercept to differ across groups. A significant difference in the predictive accuracy of the competing models indicates that the model with different regression lines is a better representation of the data. When this is the case, the interpretation of group differences is more complex (Rogosa, 1980, 1981).

The present analyses indicated that the model with parallel within-group regression lines was acceptable. The variance associated with differences in regression slopes was less than the error variance and did not approach statistical significance, $F(2,141) = 0.32, p > .724$. Therefore, the main analyses proceeded with a single pooled regression slope.

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